



# DISTRIBUTED TEMPERATURE SENSING FOR THE DETECTION OF GROUNDWATER SEEPAGE NW NATURAL GASCO SEDIMENTS CLEANUP ACTION

**Prepared for**

U.S. Environmental Protection Agency, Region 10  
1200 Sixth Avenue  
Seattle, Washington 98101

**Prepared on behalf of**

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**Prepared by**

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4225 SW Agate Lane  
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**January 6, 2016**

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## LIST OF ACRONYMS AND ABBREVIATIONS

AOC	Administrative Settlement Agreement and Order on Consent
AOS	area of seepage
DEQ	Oregon Department of Environmental Quality
DTS	distributed temperature sensing
EE/CA	Engineering Evaluation/Cost Analysis
HC&C	hydraulic control and containment
Siltronic	Siltronic Corporation
Site	NW Natural Gasco Sediments Site
USEPA	U.S. Environmental Protection Agency
WBZ	water-bearing zone
Work Plan	<i>Gasco Sediments Site – Distributed Temperature Sensing Work Plan</i>

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## EXECUTIVE SUMMARY

The groundwater to sediment pathway is a potential mechanism for contaminant transport to offshore sediments adjacent to the NW Natural Gasco and Siltronic Corporation (Siltronic) properties located on the Willamette River from river miles 6.3 to 6.8. Therefore, identification of groundwater seepage areas is important for assessing potential contaminant movement and the associated impacts on sediment remedial technology performance over time. Distributed temperature sensing (DTS) technology was tested in a pilot installation to identify areas of groundwater seepage within a focused-investigation area of the NW Natural Gasco Sediments Site (Site) shoreline. The investigation consisted of three phases of data collection that were performed in accordance with the U.S. Environmental Protection Agency (USEPA)-approved *Gasco Sediments Site – Distributed Temperature Sensing Work Plan* (Work Plan; Anchor QEA 2014). The DTS system was installed in September 2014, and Phases 1, 2, and 3 of data collection were performed in September and October 2014, January and February 2015, and March 2015, respectively, to determine the presence of seepage in the focused-investigation area under ambient conditions. The Gasco upland hydraulic control and containment (HC&C) system pumping was temporarily suspended for a 21-day period prior to and during Phase 1 data collection and for a separate 1-week period during Phase 1 data collection, for a single 4-day period during Phase 2 data collection, and for a prolonged period prior to and during Phase 3 data collection.

Data from Phases 1 and 2 enabled NW Natural to confirm that the DTS system was functioning, but due to changing surface water temperatures relative to groundwater temperatures, no definitive identification of seepage could be made from assessment of these data. Greater and more stable differences between groundwater and surface water temperatures during Phase 3 testing data allowed identification of areas of seepage (AOSs) along the cable alignment while the HC&C system pumping was temporarily suspended and restarted. During this testing period, there was an indication that groundwater seepage was occurring at several locations across the focused-investigation area while the HC&C system pumping was suspended. This finding is consistent with previous site studies that used ultrasonic seepage meters to measure groundwater seepage across most of the shoreline of the Site, including in the focused-investigation area, prior to installation of the HC&C system. During Phase 3 testing, the HC&C system pumping was restarted, and DTS data were collected to identify changes in offshore groundwater seepage caused by the pumping. Data indicate a reduction in DTS cable temperature at selected locations when the HC&C system pumping restarted. This temperature reduction is consistent with the dramatic slowing or reversal of warmer groundwater seepage

as a result of the HC&C system pumping. This change in offshore groundwater seepage measured by DTS is consistent with other empirical lines of evidence and corroborated by modeling:

- Extensive empirical groundwater potentiometric surface elevation data that show groundwater gradient reversal to the extraction wells
- Large declines in groundwater-specific conductance measured in offshore piezometers caused by groundwater seepage reversal
- MODFLOW groundwater model capture analyses showing groundwater seepage reversal throughout a large offshore area within the Site

In summary, the three phases of DTS data collection confirmed the DTS system: 1) was installed per the Work Plan (Anchor QEA 2014) and functioned correctly; 2) identified several areas of low-level groundwater seepage during temporary suspension of HC&C system pumping consistent with previous studies; and 3) detected dramatic slowing or reversal of groundwater seepage after HC&C system pumping resumed, consistent with the findings from other lines of evidence.

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## 1 BACKGROUND

NW Natural and Siltronic are developing and evaluating remedial alternatives for offshore sediments at the Site pursuant to the Administrative Settlement Agreement and Order on Consent (AOC; Comprehensive Environmental Response, Compensation, and Recovery Act, Docket No. 10-2009-0255; USEPA 2004) and the Statement of Work attached to the AOC. A key element related to the remedial alternatives development and evaluation for the Site is the understanding of the groundwater-to-sediment contamination pathway and how groundwater sources will be controlled over time to prevent recontamination of the sediments following remedy implementation. Pursuant to the second addendum to the voluntary agreement for remedial investigation and feasibility study work between NW Natural and the Oregon Department of Environmental Quality (DEQ; WMCVM-NWR-94-13; DEQ 1994), NW Natural constructed an HC&C system and placed it in operation in September 2013. The HC&C system prevents groundwater seepage from the alluvial water-bearing zones (WBZs) to offshore sediments. The system is currently in full-scale operation after extensive, multiyear testing under oversight by DEQ and in coordination with USEPA. Under current operation, the HC&C system continues to be optimized during extended Phase 2 testing per agreement with DEQ. Successful offshore groundwater seepage reversal has been measured through empirical data and corroborated by a site-specific groundwater flow model.

The Site draft Engineering Evaluation/Cost Analysis (EE/CA; Anchor QEA 2012) included an estimate of the extent of offshore seepage capture within the Site Interim Project Area based on a preliminary site-specific groundwater flow model available during development of the EE/CA. Since completion of the EE/CA, NW Natural has collected additional empirical data that confirm the reversal of offshore groundwater seepage from the alluvial zones. NW Natural has worked closely with DEQ and USEPA to refine the site-specific MODFLOW groundwater flow model based on these additional data. During a meeting on June 15, 2015, NW Natural informed the agencies that it considers the model to be calibrated. USEPA and DEQ requested (DEQ 2015a) that two additional calibration steps be taken to further refine the model, and NW Natural is working to resolve these requests. Per DEQ comments on October 6, 2015, NW Natural is continuing to work with DEQ and EPA to refine and finalize the model for multiple purposes on the project (DEQ 2015b). The requested additional calibration steps and refinements are focused on boundary conditions at the edges of the model domain and the model water balance; they are not focused on the nearshore groundwater hydraulic capture that is well documented in the alluvium. Therefore, the continuing calibration and refinement steps

are not expected to substantially change the model findings with respect to the nearshore alluvium capture zone.

One of USEPA's comments on the EE/CA (USEPA 2012) included the following statement, "The predictions of flow reversal from the groundwater model should be validated before the sediment remedy is finalized." The Work Plan (Anchor QEA 2014) was, in part, developed and implemented in response to this statement to provide an additional line of evidence to validate the existing multiple lines of evidence documenting groundwater seepage reversal and associated corroborating MODFLOW model results. The objective of the Work Plan is to identify groundwater seepage and recharge areas, if any, in a focused-investigation area within the Site Interim Project Area using DTS technology during both operation and temporary suspension of the Gasco upland HC&C system. USEPA approved the Work Plan on September 11, 2014.

## 1.1 Summary of DTS Technology

The DTS instrument calculates temperatures along the fiber optic cable by measuring the amplitudes of two color peaks formed from backscattered light that returns following a bright pulse of light from the DTS machine laser. These signals are the result of the Raman Effect, in which incident light interacts inelastically with the electrons in the glass. Following a collision with a photon from the injected light, the glass molecule emits a photon either below (Stokes) or above (anti-Stokes) the wavelength of the injected light. As the cable fiber increases in temperature, a greater number of electrons will be in higher-energy states, increasing the fraction of anti-Stokes scattering relative to the Stokes signal. The temperature of any part of the cable is determined from the ratio of anti-Stokes-to-Stokes wavelengths detected by the DTS instrument. The location of the calculated temperature is determined with high-speed electronics by measuring the elapsed time between the time of light injection and observation of the backscattered light; i.e., the two-way travel time of light reveals the distance the light traveled along the cable.

Because accurate temperature measurements can be done at thousands of locations along the cable, the DTS technology can be used to identify areas of offshore groundwater seepage based on in situ real-time measurement of the difference between groundwater temperatures in the shallow sediments and the overlying river temperatures. The DTS technology has been used by Anchor QEA, LLC, for this application at the USEPA-managed River Raisin site in Michigan and an ExxonMobil site in Baytown, Texas (Selker et al. 2014). It has also been used at another

Superfund site (Gowanus Canal) and several other locations in the United States, Canada, and Europe. The Site is a good candidate site for application of the DTS technology because there are typically long periods of time when the Willamette River water temperatures are significantly different than the groundwater temperature, which has a small seasonal variance. Additionally, the ability to track temperatures continuously through time over extended durations is helpful to assessing potential impacts of changes in HC&C operation.

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## **2 SUMMARY OF DTS FOCUSED INVESTIGATION DATA COLLECTION**

NW Natural performed the focused DTS investigation in accordance with the Work Plan (Anchor QEA 2014) in three phases in September and October 2014, January and February 2015, and March 2015, respectively. The remainder of Section 2 summarizes the DTS focused investigation installation, calibration, and each phase of data collection.

### **2.1 DTS Installation and Data Collection Summary**

DTS data were collected to assess offshore groundwater seepage conditions during time periods when the HC&C system pumping was temporarily suspended and subsequently restarted. The DTS fiber optic cable array was installed in a portion of the USEPA-approved Site Interim Project Area (the focused-investigation area), and data collection was performed during fall 2014 and winter 2015 over a wide range of Willamette River temperatures and flow conditions. The DTS system was calibrated prior to installation using ice and warm-water baths paired with highly accurate thermometers that measure to a tolerance of 0.01 degree Celsius and contributed less than 0.005 degree Celsius in temperature variability over the three phases of testing. The DTS cable and supporting equipment were installed by SelkerMetrics, LLC, and operated by Anchor QEA under the direction of SelkerMetrics. DTS data evaluations, including the identification of seepage zones, were performed by SelkerMetrics in accordance with the Work Plan (Anchor QEA 2014).

In accordance with the Work Plan (Anchor QEA 2014), diver reconnaissance was performed to verify that the DTS fiber optic cable was buried. Two diver surveys and a numerical depth analysis of temperature data were conducted to verify that the DTS cable was properly buried. The diver surveys occurred on February 20 and April 10, 2015, under USEPA oversight. Portions of the cable that were not buried or alternatively were exposed above the river low-water mark shown in Figure 1 are excluded from the data evaluation and findings.

Both river water and groundwater temperatures were measured as part of the DTS investigation as close as feasible to the focused-investigation area. River water temperature data were collected from on-site stilling wells located on the inside of the offshore gangway of the dock, which is located approximately 750 feet downriver from the focused-investigation area; from exposed portions of the DTS cable; and from the U.S. Geological Survey Morrison Street gauge, which is located approximately 6.25 miles upriver of the focused-investigation area. Unburied portions of cable provide the most representative river water temperatures for

this study due to their direct exposure to river water in close proximity to the water-sediment interface and their spatial coverage throughout the focused-investigation area. Groundwater temperature data were collected from a nearshore piezometer (PZ9-75) screened in the Upper Alluvium WBZ. The groundwater temperatures measured at PZ9-75 were compared to other wells screened in the Upper Alluvium WBZ and were determined to be representative. The Upper Alluvium WBZ is the formation that is in direct contact with the river in the focused-investigation area. The locations of the exposed cable segments and PZ9-75 are shown in Figure 1.

Between September 15 and 18, 2014, a Sensornet Oryx DTS instrument that offers a spatial resolution of 6.6 feet and fiber optic cable array were installed at the Site. The fiber optic cable was installed in the focused-investigation area of the Site in the zig-zag pattern shown in Figures 1, 2, and 3. Twelve hundred feet of cable were installed below the high water line. The cable layout extends along approximately 300 linear feet of shoreline and extends into the river approximately 220 feet from the top of bank. The cable was installed by a diver in accordance with the Work Plan (Anchor QEA 2014) under USEPA oversight. The design intent was to bury all sections of the cable approximately 2 inches below the mudline, but the grain size and compaction of the surface sediment prevented cable burial in some areas. As noted earlier in this section, all unburied portions of the cable were identified. Those portions of unburied cable adjacent to AOSs were used to determine river temperature, while the remainder of the unburied cable was excluded from the evaluation. On September 19, a 5-hour period of data collection confirmed that the DTS instrument was properly analyzing and recording temperature data. Prior to any formal data collection, the DTS system's function was assessed, and hot and cold calibration baths were established. These steps ensured that the integrity of the cable had not been compromised and that the data collected by the DTS system were high quality. With approximately 1,200 feet of cable placed in the focused-investigation area and temperature data collected every 20 minutes, approximately 13,000 temperature-location data points were generated per day.

## **2.2 Phase 1 Data Collection**

Phase 1 data collection was performed between September 25 and October 15, 2014. During Phase 1, the range of river water temperatures was 62 to 66 degrees Fahrenheit (as measured at areas of exposed cable), and the groundwater temperature was 59 degrees Fahrenheit (as measured in nearshore piezometers), providing a temperature differential of 3 to 7 degrees Fahrenheit. The HC&C system pumping was temporarily suspended for two periods over this

phase of data collection. The first period of HC&C system pumping suspension was from 1120 hours on September 11 through 1200 hours on October 2. The second period of HC&C system pumping suspension was from 1000 hours on October 7 through 0945 hours on October 13. No clear indications of groundwater seepage were observed during this period of data collection due to the small temperature differential between the river and groundwater temperatures and rapid cooling of the river, as shown in Figure 4.

On October 20, 2014, during a period of low river elevation, exposed portions of the DTS cable installed along the upper shoreline area were buried to the target depth by landside personnel working on foot. These were segments of the cable that could not be buried by the diver due to the coarse-grained or compacted nature of the surface sediment and shallow water present during the initial installation. Figures 1, 2, and 3 show the burial condition of the cable (buried in fines, buried in coarse sediment, or exposed) after this work was completed.

### **2.3 Phase 2 Data Collection**

Phase 2 data collection was performed between January 29 and February 6, 2015. Figure 5 depicts river water and groundwater temperatures during this phase of data collection and shows the periods when the HC&C system pumping was suspended and re-initiated. During Phase 2 the river water temperatures ranged from 46 to 48 degrees Fahrenheit, and the groundwater temperature remained constant at 58 degrees Fahrenheit, which provided a differential of 10 to 12 degrees Fahrenheit. The HC&C system pumping was suspended from 0700 hours on February 3 through the end of Phase 2 data collection. The river temperature began rapidly warming on February 5, which began to impact SelkerMetrics' ability to definitively identify AOSs; therefore, Phase 2 testing was halted on February 6 (resulting in 4 days of data collection while the HC&C system was turned off). SelkerMetrics and Anchor QEA continued to monitor the river water temperatures after February 6, and the river temperatures decreased, allowing for a third phase of data collection.

### **2.4 Phase 3 Data Collection**

Phase 3 data collection was performed between March 1 and 16, 2015. During Phase 3 the river water temperatures ranged from 47 to 53 degrees Fahrenheit, and the groundwater temperature was 58 degrees Fahrenheit, which provided a differential of 5 to 11 degrees Fahrenheit. As shown in Figure 5, Phase 3 data collection occurred while the HC&C system pumping was suspended. At 0915 hours on March 10, the HC&C system pumping was re-initiated. The HC&C system pumping was suspended for 34 days during and prior to March 10, which is a

significantly longer period of time without hydraulic control than the 21-day suspension of pumping during Phase 1 and the 4-day suspension period during Phase 2. Figure 5 shows the increase in river temperatures that occurred after March 11.

## **2.5 Deviations from the Work Plan**

No significant deviations from the USEPA-approved Work Plan were made. The Work Plan does state that temperature measurements were anticipated to be collected through January 2015. However, due to atypical river temperatures and conditions, DTS temperature measurements were made and analyzed through March 16, 2015 in coordination with USEPA and DEQ (DEQ 2015c). Additionally, DTS data were assessed every 20 minutes rather than the 10-minute temporal resolution identified in the Work Plan to reduce the standard deviation of measurements made by the DTS system and create a stronger linkage between changes in river water temperatures to longer-term environmental shifts (e.g., tide cycles and diurnal fluctuations).

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## 3 RESULTS

Section 3 provides a summary of the DTS focused investigation results for each phase of data collection.

### 3.1 Phase 1 and 2 Results

Data from Phases 1 and 2 enabled NW Natural to confirm that the DTS system was functioning correctly, but due to changing surface water temperatures relative to groundwater temperatures, low temperature differentials during Phase 1, and a short period of HC&C system suspension during Phase 2, no definitive identification of groundwater seepage or recharge could be made from assessment of these data.

### 3.2 Phase 3 Results

Periods of stable and still-cool water temperature following Phase 2 data collection facilitated the third and final phase of DTS data collection. Phase 3 data identified offshore groundwater seepage in six broadly distributed AOSs along the fiber optic cable array between March 1 and 16, 2015. The six AOSs were identified based on elevated fiber optic cable temperatures relative to the measured river temperatures during the period that the HC&C system pumping was suspended. Figure 2 shows the differential temperatures along the full alignment of the cable and the six AOSs identified on March 9. AOSs occurred in sections of cable buried in fine sediments where there were positive temperature differentials, as represented by the warm colors along the cable layout shown in Figure 2. Temperature data from exposed portions of the cable and for portions of the cable located above the river low-water mark were excluded from the data evaluation.

After resuming HC&C system pumping on March 10, Phase 3 data identified that groundwater-to-river temperature differentials in the AOSs were reduced, reflecting groundwater gradient reversal and the resulting infiltration of cold river water into the surface sediments. This finding is shown in Figure 3, which depicts temperature differentials on March 11. In Figure 3 most of the cable away from shore is slightly warmer than in Figure 2, due to warming river water temperatures, but the AOSs have cooled or remained the same. Cable nearshore is affected by differing river depths through time and exposure to air, so the nearshore cooling does not provide information regarding seepage changes. The cooling at AOSs is not prominent due to the reduced differentials between river and groundwater temperatures caused by the rising river temperature.

An area of interest was also identified near the shoreline at the second-most southerly vertex of the cable alignment. Unlike other portions of the cable alignment near the shoreline, this area of interest was fully submerged and buried in accordance with the Work Plan during Phase 3 data collection. Figures 2 and 3 show this area of interest as a red-colored temperature differential greater than 0.25 degree Fahrenheit. This area of interest did not show any response to pumping by the HC&C system during Phase 3.

Temperature differentials between groundwater and river water during the three phases of testing varied from 3 to 12 degrees Fahrenheit. However, it is important to note that temperature differentials between AOSs (as measured in surface sediment porewater via the DTS cable) and the river are much smaller. This difference is due to two factors: 1) the thermal mass of the sediments prevents rapid changes in sediment porewater temperatures, and 2) the processes of thermal conduction, convection, and advection transfer heat to river water leading to a cooling of the surface sediments. The modest temperature differentials observed at the AOSs are a result of these thermal processes partially masking the heat transfer to the sediments by low-flows of groundwater seeps.

Additional evidence of the effect of the HC&C system on groundwater seepage can be identified based on the differences in temperatures measured at buried segments of cable in AOSs, buried segments of cable with no seepage, and unburied segments of cable adjacent to AOSs. Figure 6 presents temperature data associated with these three DTS cable burial classifications and the river water temperature between February 20 and March 17, 2015. These river temperature data (green line) are different than the river water temperatures measured at the sediment-water interface along portions of unburied cable near AOSs (blue line) in the focused-investigation area, likely due to depth and spatial variability, but are included to show the temperature history prior to Phase 3. Changes in river water temperatures at the Site (green line) are reflected differently in the DTS cable depending on whether the cable is buried in an area without groundwater seepage (black line), or buried in an AOS (red line). Buried cable in areas without groundwater seepage reflects changing river temperatures with a smoothing and lag due to the isolation of these areas from the water column through burial in the sediments. Cable buried in an AOS (red line) also shows smoothing and lag due to isolation but additionally shows warming by seeping groundwater until the HC&C system resumed pumping on March 10. That is, the red line is higher than the black prior to pumping, but red and black converge several hours after pumping resumes. In summary, evidence of seepage in Figure 6 includes the following:

- Unburied cable near AOSs (blue line): After March 1, 2015, changes in river temperature are reflected almost immediately in the portions of cable that are unburied or buried in coarse sediment.
- Cable buried in fine sediment (black line) but without evidence of seeps: These sections respond to changes in river water temperature more slowly, reflecting the isolation of cable in these sections from the river water.
- Cable buried in AOSs (red line): These sections also change more slowly than surface cable but additionally show warming, suggesting groundwater emergence prior to resuming HC&C system pumping on March 10, 2015. As river temperatures increased after March 10, the temperature of the DTS cable in the AOSs would be expected to remain warmer than other buried cable, but it does not, suggesting that groundwater discharge was dramatically slowed or reversed due to the restart of HC&C system operations on March 10.

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## 4 CHALLENGES

During the DTS focused investigation, the following challenges were identified and overcome:

- First, burial of the DTS cable in accordance with the Work Plan (Anchor QEA 2014) was not possible in some areas of the focused-investigation area due to the presence of rocks and very coarse sediment. Therefore, to ensure data collected from these areas were excluded from the DTS data evaluation, multiple lines of evidence were used to identify and corroborate these areas, including diver observations, landside personnel observations during low tide events, and DTS data evaluations performed by SelkerMetrics.
- Second, an unusually warm winter contributed to modest temperature differentials between the groundwater and river water temperatures, which impacted data collection.
- Third, river temperatures fluctuated frequently and substantially during the periods in which the study was carried out, in contrast to most winters in which there are prolonged cold spells.

The burial and placement of the DTS cable can be improved if future deployment is proposed. To more fully evaluate whether the substrate is suitable in proposed deployment areas, the following additional steps could be performed:

- Shoreline visual surveys during low water conditions
- Water-based probing and/or surface grab samples to further delineate areas of suitable substrate
- Focused geophysical survey of substrate characteristics

The groundwater-to-surface water temperature differentials can likely be improved if additional DTS studies are performed at the Site. Smaller-than-anticipated temperature differentials were present over the course of Phase 1 and Phase 2 data collection due to river temperatures uncharacteristically higher than historically documented during the winter months. It is likely that any proposed DTS investigations during the winter months would encounter much colder river water temperatures closer to historical norms (as generally observed during the Phase 3 data collection), providing greater temperature differentials. Similarly, colder winter river temperatures are typically maintained for prolonged periods, which would reduce the higher-than-anticipated river temperature fluctuations observed throughout the DTS data collection.

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## 5 CONCLUSIONS

The DTS technology was successfully applied at the Site, and the following objectives were achieved:

- The DTS fiber optic cable was successfully installed and field-verified along the focused-investigation area where the cable could be properly buried.
- Groundwater seepage was detected at six AOSs in the focused-investigation area during temporary HC&C pumping suspension during Phase 3. The detection of AOSs is consistent with other empirical data (offshore seepage meters and groundwater elevation measurements in the uplands and offshore) and the site-specific groundwater model.
- Groundwater seepage was dramatically slowed or reversed in the six AOSs following re-initiation of HC&C system pumping during Phase 3.

Use of DTS technology field-verified that offshore groundwater seepage in the focused-investigation area occurs during shutdown of the HC&C system, and this seepage is dramatically slowed or reversed during operation of the HC&C system. The ability of DTS to detect seepage and its response to pumping under challenging site conditions is evidence that this technology is a viable option for the assessment of seepage throughout the Site Interim Project Area and may be a potentially, useful tool for further supporting the development and evaluation of remedial alternatives for the Site and the design of the selected remedy.

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## 6 REFERENCES





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# FIGURES






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-  Piezometer Location
-  Interim Project Area Boundary
-  Gasco Sediment Site Area of Interest (Final Work Plan [Anchor QEA 2009])
-  Federal Navigation Channel

#### DTS Cable Layout

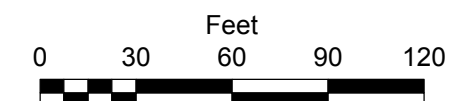
-  Buried in Fines
-  Buried in Coarse Sediment
-  Exposed
-  Low Water Mark - March 1-16, 2015 (6.03 ft COP)
-  High Water Mark - March 1-16, 2015 (9.29 ft COP)

#### Areas of Seepage

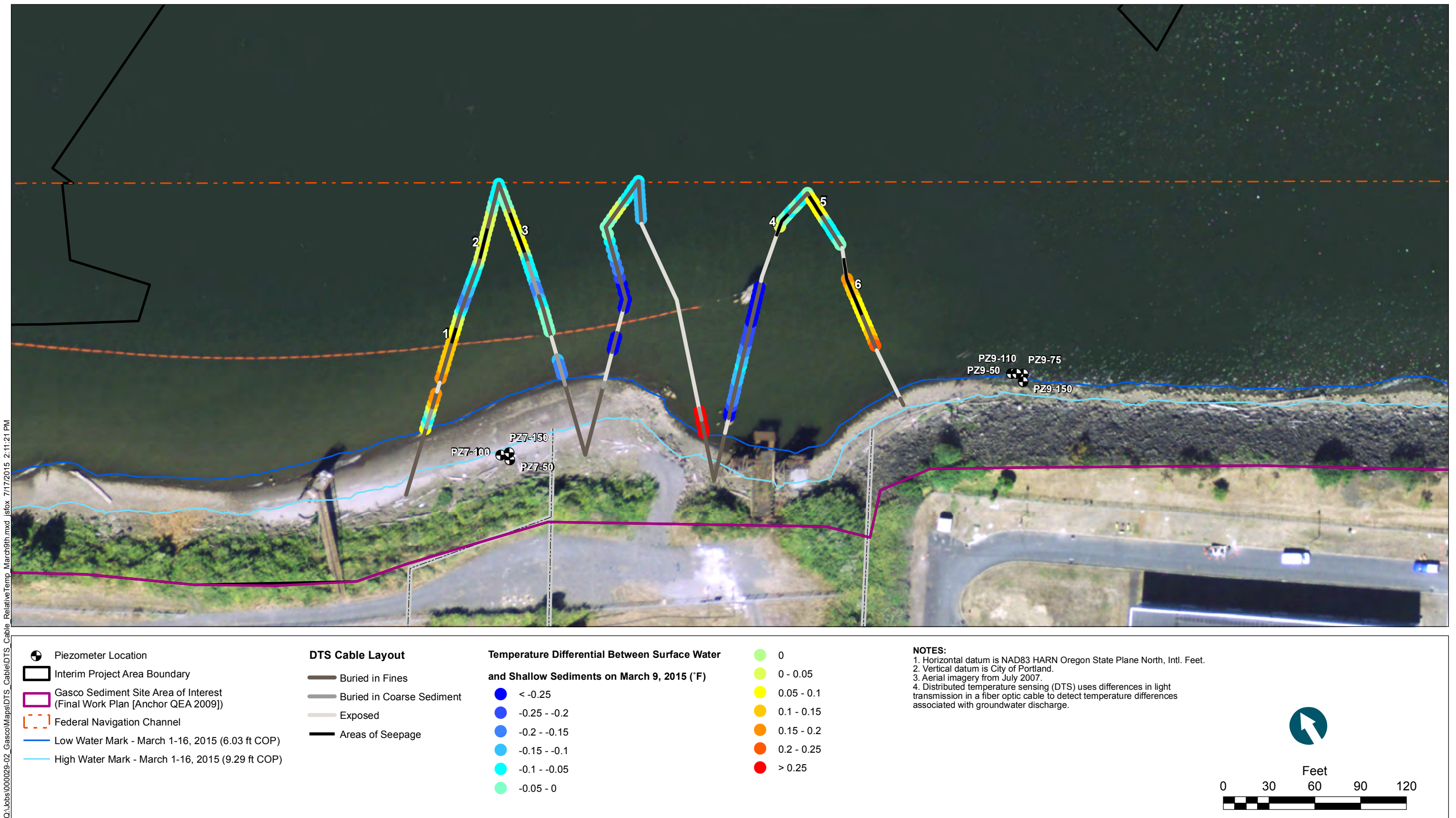
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#### NOTES:

1. Horizontal datum is NAD83 HARN Oregon State Plane North, Intl. Feet.
2. Vertical datum is City of Portland.
3. Aerial imagery from July 2007.
4. Distributed temperature sensing (DTS) uses differences in light transmission in a fiber optic cable to detect temperature differences associated with groundwater discharge.

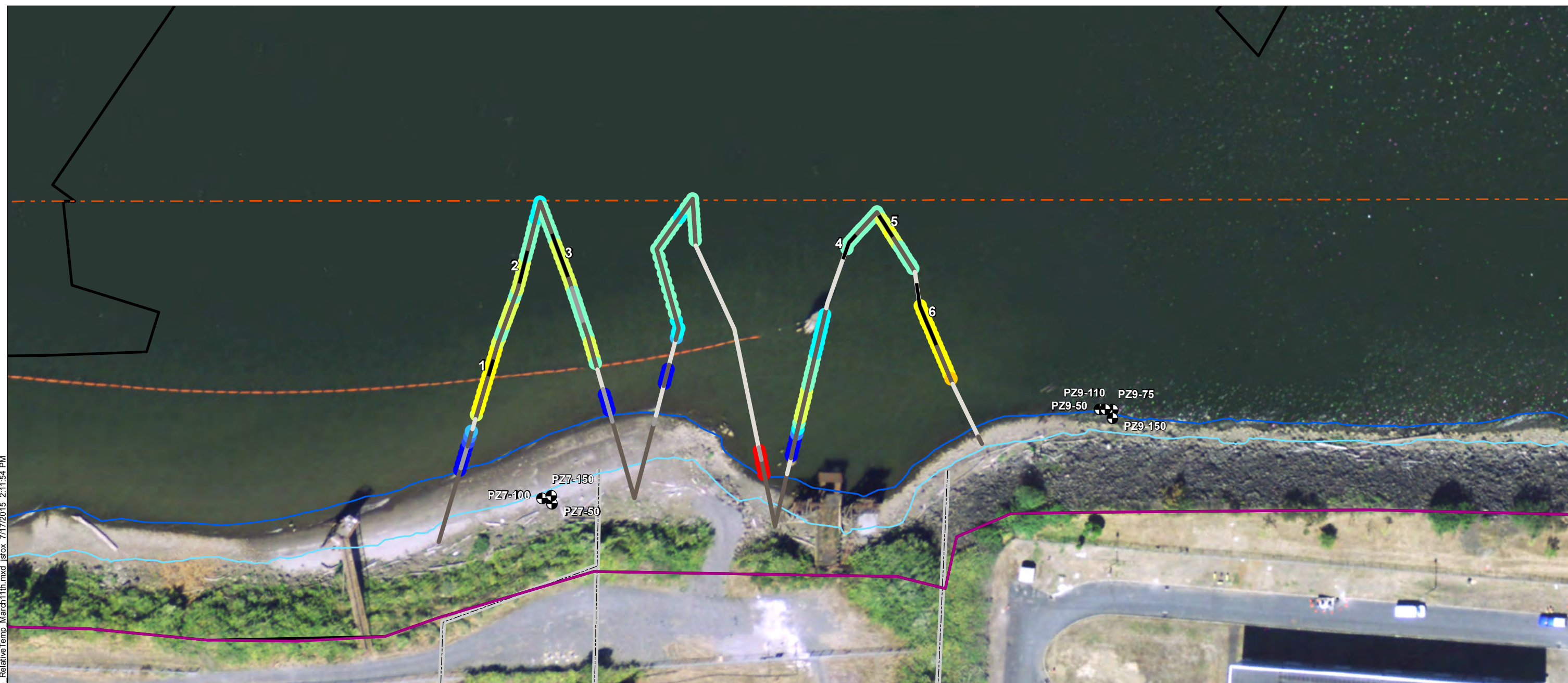


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**Figure 2**  
Differential Temperatures During HC&C Shutdown (March 9, 2015)  
Distributed Temperature Sensing for the Detection of Groundwater Seepage  
NW Natural Gasco Sediments Cleanup Action

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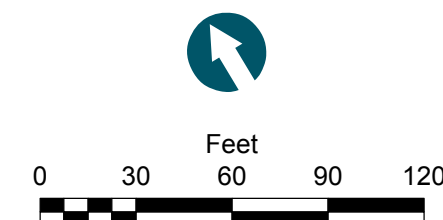
- Piezometer Location
- Interim Project Area Boundary
- Gasco Sediment Site Area of Interest (Final Work Plan [Anchor QEA 2009])
- Federal Navigation Channel
- Low Water Mark - March 1-16, 2015 (6.03 ft COP)
- High Water Mark - March 1-16, 2015 (9.29 ft COP)

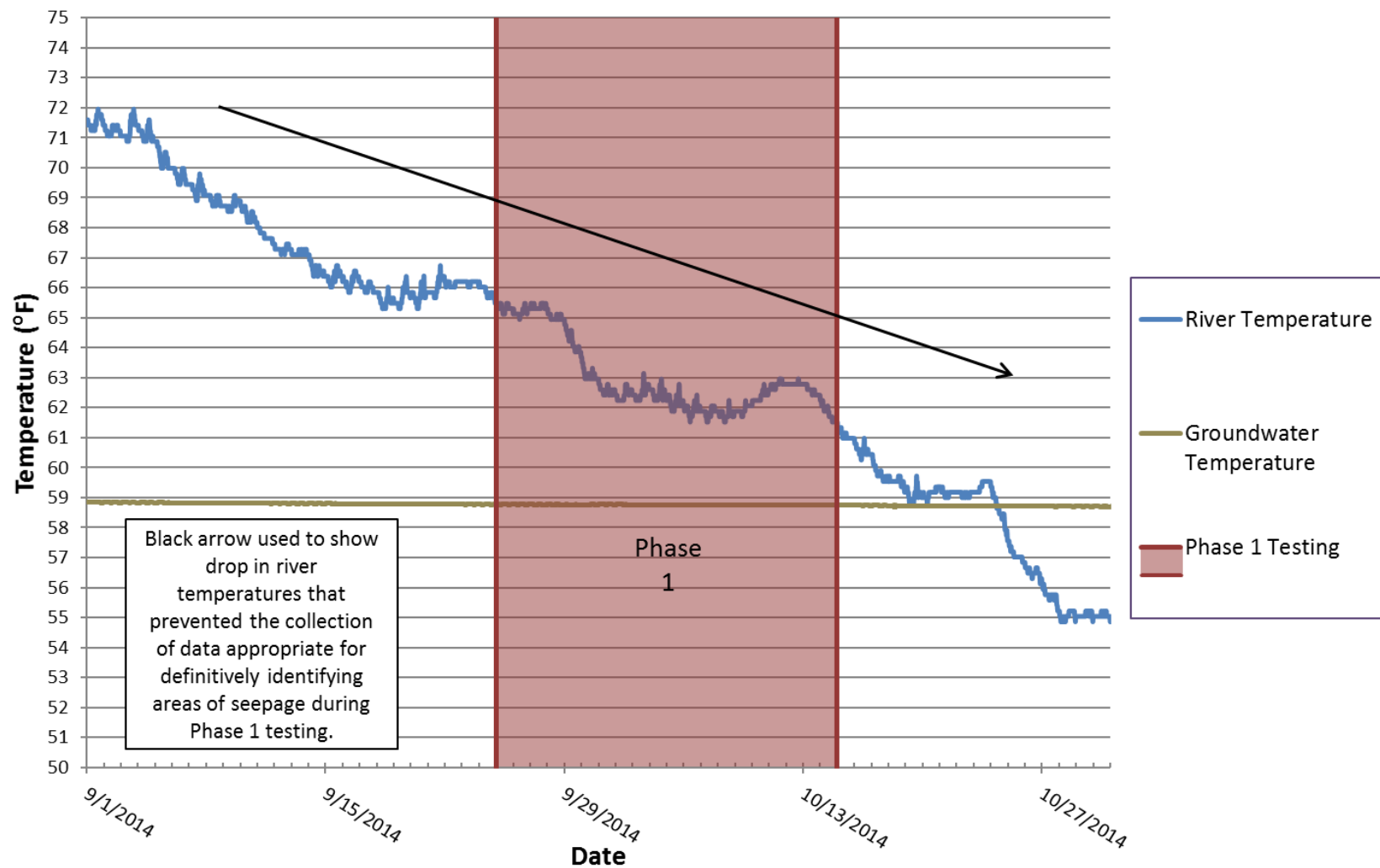
- DTS Cable Layout**
- Buried in Fines
  - Buried in Coarse Sediment
  - Exposed
  - Areas of Seepage

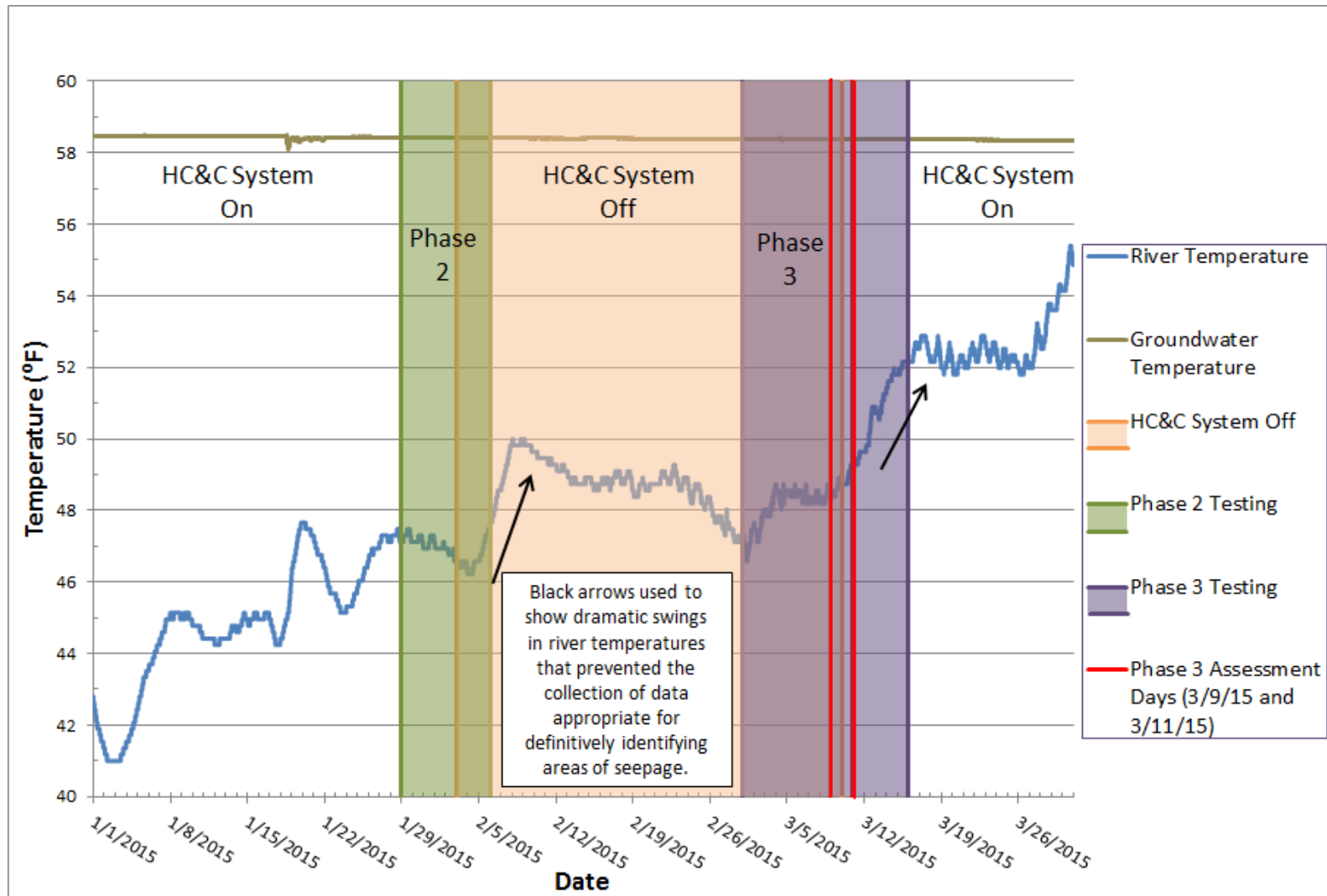
- Temperature Differential Between Surface Water and Shallow Sediments on March 11, 2015 (°F)**
- < -0.025
  - 0.25 - -0.2
  - 0.2 - -0.15
  - 0.15 - -0.1
  - 0.1 - -0.05
  - 0.05 - 0

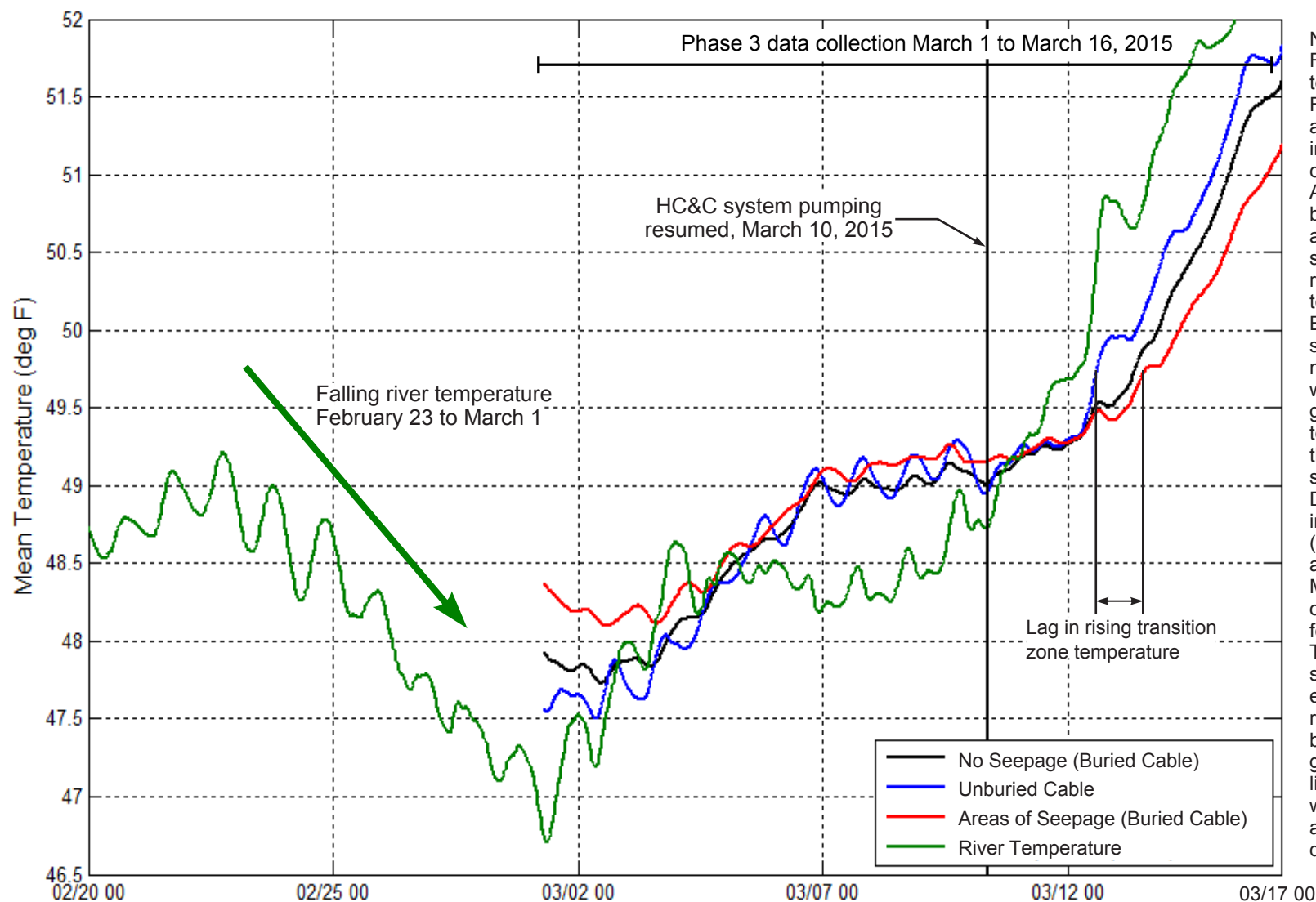
- 0
- 0 - 0.05
- 0.051 - 0.1
- 0.1 - 0.15
- 0.15 - 0.2
- 0.2 - 0.25
- > 0.25

**NOTES:**  
1. Horizontal datum is NAD83 HARN Oregon State Plane North, Intl. Feet.  
2. Vertical datum is City of Portland.  
3. Aerial imagery from July 2007.  
4. Distributed temperature sensing (DTS) uses differences in light transmission in a fiber optic cable to detect temperature differences associated with groundwater discharge.









Note: Falling river water temperatures between February 23 and March 1 are reflected most immediately in unburied cable (blue line) adjacent to AOSs when data collection began. Buried cable in areas without groundwater seepage (black line) also reflect changing river temperature with a lag. Buried cable in areas of seepage (red line) show the most lag because the cable was warmed by seeping groundwater. As river temperatures increased, the temperature in sediment (measured in DTS cable) gradually increased. The buried cable (black and red lines) show a lag, particularly beginning March 12; HC&C operations had resumed following March 10. Temperatures in areas of seepage would be expected to increase rapidly due to warming from both surface water and groundwater, but the red line actually exhibits lag, which indicates the absence of groundwater discharge.